[i] Environmental Technologies Contributing to Achieving Carbon Neutrality

Electric Drive and Control for Two-wheeled Vehicles to Protect Environment and Enhance Safety and Comfort

Recently, two-wheeled vehicles are following a similar path to that of their four-wheeled counterparts, with the pace of electrification being accelerated by demand for environmental protection measures as well as safety and comfort. This includes both powertrain electrification aimed at achieving carbon neutrality and other forms of environmental protection and the electric control of brakes and suspension in pursuit of safety and comfort. Accordingly, Hitachi Astemo, Ltd. has stepped up its work on electric drive and control for two-wheeled vehicles. This article presents the range of motorcycle products available from Hitachi Astemo in the context of this trend toward electrification for environmental protection and electric control for safety and comfort, and also describes the company's plans for the future.

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1. Introduction

The accelerated shift toward electric vehicles (EVs) that has been happening over recent years in pursuit of carbon neutrality also applies to two-wheeled vehicles. This trend is spreading around the world and has included the introduction at the national and regional levels of environmental, energy, and other policies aimed at fostering the electric motorcycle industry.

Driven by a demand for safety and comfort, the use of electric control has also been expanding year by year. Safety requirements in particular have been rising internationally, and anti-lock braking systems (ABS) are becoming mandatory in many countries around the world. Likewise, further advances are anticipated in safety and comfort equipment, as exemplified by the commercialization in 2021 of advanced driver assistance system (ADAS) products for two-wheeled vehicles. The demand for motorcycles that are comfortable and that feel good to ride is expected to continue, with electrically controlled suspension increasingly being adopted to improve rider comfort.

This article describes the work being done by Hitachi Astemo, Ltd. on electric drive for two-wheeled vehicles to improve their environmental performance as well as its work on electric control for safety and comfort.

2. Work on Electric Drive to Improve Environmental Performance

This section describes the work being done on electric powertrains (inverter, motor, and gearbox) for the electrification of two-wheeled vehicles with the aim of reducing carbon dioxide (CO_2) emissions by 2030 and achieving carbon neutrality in 2050.

2. 1
Market Trends for Electric Powertrains

Over recent years, local manufacturers and venture businesses have sought to establish a market for electric motorcycles, primarily aimed at the "FUN" area in Europe and the commuter market in places such as China, the Association of South East Asian Nations (ASEAN), and India. While the electrification of commuter vehicles is crucial to reducing CO_2 emissions in the large markets of Asia, the available models largely fall into two main categories that prioritize performance and price respectively (see **Figure 1**).

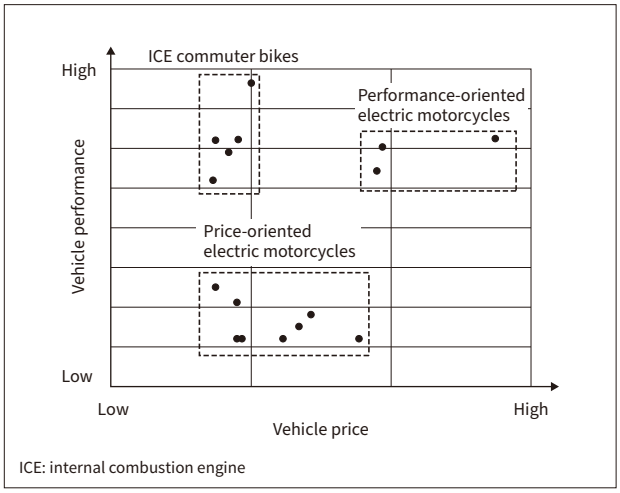
In China, where electrification is well advanced, two-wheeled electric vehicles are now being produced in the tens of millions annually, including around a hundred thousand price-oriented commuter models. However, few electric powertrains offer the combination of power and performance with low vehicle cost needed as to serve as a primary means of getting around in the same way that is possible with internal combustion engine (ICE) models. As such, it seems likely that increasing electrification and reducing CO_2 emissions will take some time in other Asian nations, and therefore work is continuing on technologies for improving the fuel economy of ICE powertrains to meet the requirements of the On-Board Diagnostics Second Generation (OBD II) and Corporate Average Fuel Efficiency 2nd (CAFE 2nd) standards.

2. 2
Electric Powertrain Requirements

As with four-wheeled vehicles, lithium-ion batteries are an important factor in vehicle range and price. In addition to supply shortages of graphite and rare earth metals, it is anticipated that the trend toward reducing costs will be frustrated by many challenges, such as how to control logistics costs in the manufacturing stage. Accordingly, it is predicted that the inverters, motors, gearboxes, and other components used in electric powertrains will be among the areas where pressure to cut costs will continue to intensify, creating a need not only for advances in battery technology, but also for the optimization of electric powertrains at the system level.

Figure 1 — Performance and Price Brackets for Electric Motorcycles in Asian Markets

Electric motorcycles for commuter use in Asian countries tend to fall into two main categories that prioritize performance and price respectively. However, few electric options offer the combination of performance and price that can be found among ICE motorcycles.



ICE: internal combustion engine

2. 3
Examples of Electric Powertrains

This section looks at work being done by other companies on electric powertrains for commuter motorcycles, focusing on three particular areas seen as offering considerable scope for improvement, namely power supply voltages, cooling, and packaging.

Performance-oriented electric powertrains feature power supply voltages of 60 V or more together with water or forced-air cooling, with many instances of onboard motor configurations in which the gearbox forms part of the package. Packaging has been developed with a reduced unsprung weight to enhance ride comfort together with a power supply voltage that is sufficiently high relative to the back electromotive-force (EMF) voltage to ensure an adequate maximum speed and a cooling system that can cope with the amount of heat generated, which depends on power output.

In contrast, price-oriented electric powertrains use natural cooling and a power supply voltage of less than 60 V. In most cases, the packaging features either a direct-drive in-wheel motor or a side-wheel motor paired with a gearbox. They use less expensive electrical isolation systems with simple cooling and drive mechanisms, accepting the consequent loss of maximum speed and output characteristics.

Electric powertrains come in many different combinations and no de-facto standard has yet emerged on how best to satisfy the user needs for both vehicle performance and price. It is expected that both original equipment manufacturers (OEMs) and suppliers will continue working on further optimization.

2. 4
e-Axle as Optimal Package

The trend in four-wheeled vehicles is toward combining the inverter, motor, and gearbox into a single "e-Axle" that represents the optimal package for an electric powertrain that can offer an alternative to ICE vehicles. Unfortunately, the limited installation space available on two-wheeled vehicles as well as heat balance and cost-viability issues pose even higher hurdles than those for four-wheeled vehicles.

Accordingly, Hitachi Astemo has been considering an optimal e-Axle that satisfies the demands of the market, designing the required functions to be smaller, lighter, and

less expensive so as to make the most of integrating the different parts into a single component, with system control that is as efficient as it can be overall.

3. Work on Safety, Comfort, and Electric Control

3. 1
Electric Control of Braking

ABS is the typical example of a system for two-wheeled vehicle braking based on electric control. The ABS unit is made up of a solenoid valve, electric motor, pump, and electronic control unit (ECU), with sensors on the wheels being used to obtain wheel speed. It prevents skidding by using the master cylinder to increase, decrease, or maintain the hydraulic pressure applied to the calipers when it determines that the wheels are about to lock.

While the indirect-type, motor-driven-type, and circulation-type modulators have all been used in past mass-produced ABSs for two-wheeled vehicles, the circulation-type ABS now predominates.

Hitachi Astemo's ABS, a modified circulation-type ABS originally developed for four-wheeled vehicles, was deployed for the first time in a production motorcycle on the FORZA* scooter of Honda Motor Co., Ltd. in 2000.

* FORZA is a registered trademark of Honda Motor Co., Ltd. in Japan.

Hitachi used four-wheel ABS as a base for the second- and third-generation ABSs and then for the fourth generation switched to a system design specifically for two-wheelers that satisfied their important requirements for lighter weight and smaller size so as to expand the range of motorcycles on which ABS could be used. The fifth generation of ABS is now in commercial production with two main variations, namely two-channel systems that control both front and rear wheels and one-channel systems that only work on the front wheel and were developed to be easier to fit on smaller two-wheeled vehicles (see **Figure 2**).

3. 2
ABS Regulation and State of Market Growth

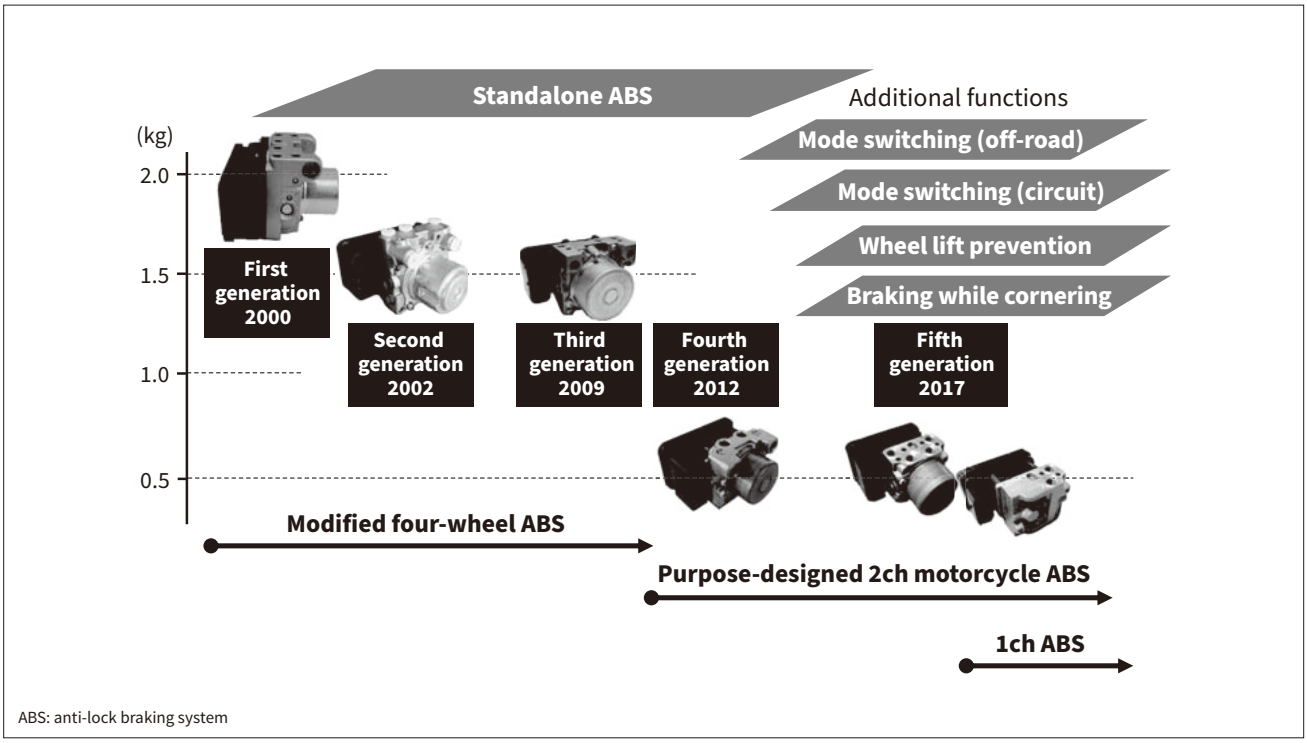
Behind these evolutional generations and series of ABS products has been an increase in the number of vehicles that are fitted with the technology. A major factor in this growth has been the regulation of advanced braking systems, first by the European Union in 2016 and subsequently by Brazil, Japan, India, and China. The range of vehicles covered by these requirements is expected to grow further, with Thailand scheduled to introduce such regulations in 2024.

3. 3
Advances in Electric Braking

One advance in ABS functionality has been its use to prevent "rear lift," a problem specific to motorcycles whereby

Figure 2 — Evolution of ABS for Motorcycles

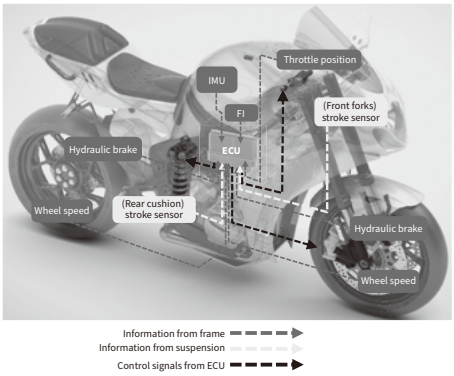
Equipping motorcycles with ABS has been made easier by the availability of purpose-designed units that are significantly smaller and lighter. Functionality has also been enhanced by incorporating control practices that address the specific dynamics of two-wheeled vehicles (wheel lift prevention and braking while cornering are controlled using an acceleration sensor).



ABS: anti-lock braking system

Figure 3 — EERA Series

The EERA series of electrically controlled suspension products was developed to overcome conflicting objectives and provide riders with the ultimate in comfort and enjoyment.



EERA Damping Force

The amount of damping is adjusted to suit different riding conditions

EERA Steering

Steering damping is optimized based on bike dynamics and behavior

EERA HEIGHTFLEX

The ride height is raised when the bike is moving and lowered again when stopping to improve riding performance while making it easy for the rider to place their feet back on the ground

EERA Ride Height

The ride height is adjusted based on the load, such as when carrying a pillion passenger or other additional load

EERA: electronically equipped ride adjustment FI: fuel injection IMU: inertial measurement unit ECU: electronic control unit

the rear wheel loses contact with the road under braking. This is done by obtaining a more detailed understanding of what is happening to the vehicle, considering acceleration as well as speed, and by tuning for each vehicle. Another advance, intended to enhance the braking performance of motorcycles during cornering, is to improve safety and comfort by giving the rider the ability to select different braking performance modes based on their riding situation using the human machine interface (HMI) made available by converting other devices to electric control.

Meanwhile, the self-pressurizing function used in electronic stability control (ESC) for four-wheeled vehicles is now starting to be used on two-wheeled vehicles also. While at present it is generally only available on high-end models, Hitachi intends to continue with the development of braking systems that will expand the use of this technology to smaller motorcycles with the aims of improving stability and reducing traffic accidents.

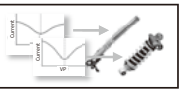
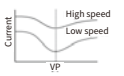
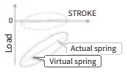
3. 4
Electric Control of Suspension

The adoption of electrically controlled suspension was driven by a desire to provide riders with the ultimate in comfort and enjoyment. The technology is being deployed in a series of products under the name "electronically equipped ride adjustment" (EERA). EERA Damping Force went on the market in 2018, then went on to expand to the EERA Ride Height (from 2019), EERA Steering (from 2020), and EERA HEIGHTFLEX (from 2021) (see **Figure 3**).

While electrically controlled suspensions have been widely used in four-wheeled vehicles, deploying them on two-wheeled vehicles requires that differences in weight and dynamic characteristics be taken into account. Electric control was successfully implemented in EERA while maintaining the core performance of existing conventional dampers by designing electronically controlled hydraulic valves specifically for this purpose in pursuit of the ideal ride feel for two-wheeled vehicles. Product appeal was further

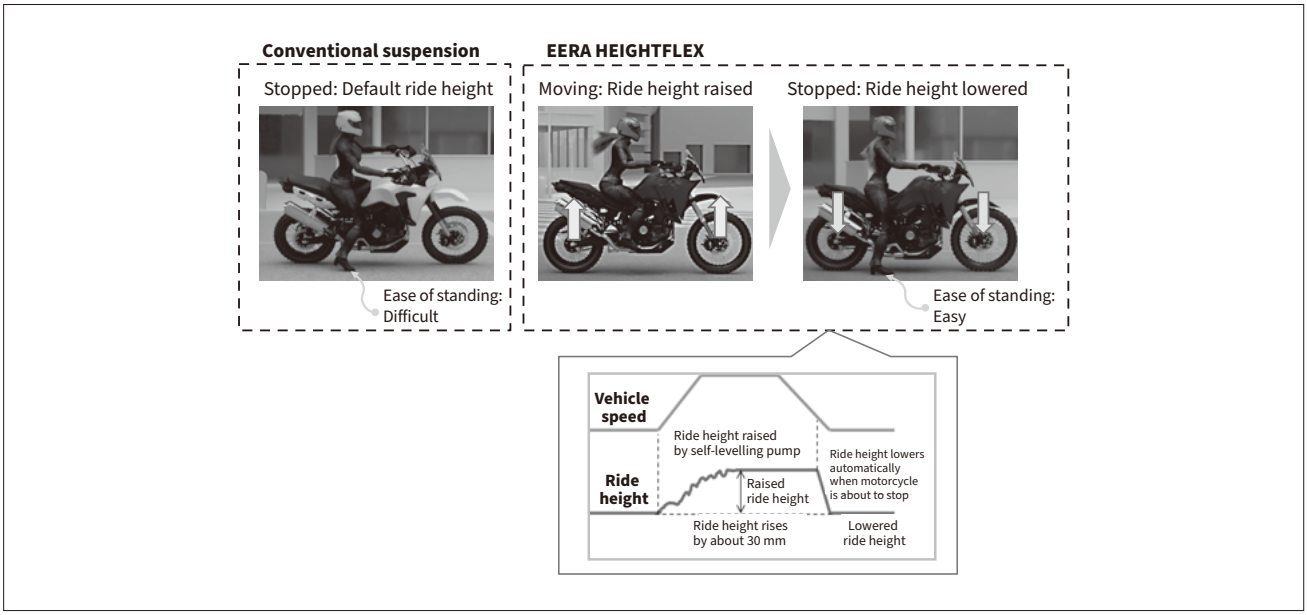
Figure 4 — Main EERA Control Features

All control is implemented using original Hitachi techniques.

VP-MAP control	Determines optimal damping characteristics to suit different riding conditions 	Jump landing control	Improves bottoming toughness when landing a jump 
Speed-dependent control	Optimizes damping for different speeds 	Skyhook control	Provides both ride comfort and stability by controlling bottom of spring to keep top of spring steady 
Deceleration control	Maintains bike stability during braking 	Virtual spring rate control	Adjusts the damping force to simulate a variable spring rate 
HEIGHTFLEX control	Provides ideal ride height when riding but lowers the bike on stopping 	Automatic load adjustment	Estimates the load and automatically adjusts the ride height accordingly 

VP-MAP: velocity of piston map

Figure 5 — EERA HEIGHTFLEX
EERA HEIGHTFLEX helps many riders feel more confident by being able to place their feet on the ground.



enhanced by using Hitachi's own original control technique to achieve maximum suspension performance (see **Figure 4**).

Development of these products involved both simulation and actual vehicle evaluation, with one of the strengths of Hitachi Astemo in this regard being the availability of riders able to conduct such evaluation at a level equal or higher to that of OEMs.

3. 5
Market Launch of New EERA HEIGHTFLEX

The latest model in the EERA series described above is the EERA HEIGHTFLEX, which was launched in 2021. This system achieves a high level of stability by raising the vehicle height when the motorcycle is in motion, lowering it again when stopping to make it easy for the rider to place their feet back on the ground.

The value of this system lies in how it achieves a high-level mix of riding performance and ease of standing. No rider considering the purchase of a large and heavy high-end motorcycle will choose a model from which their feet cannot reach the ground. Likewise, they will think twice about buying one that makes standing awkward, however attractive it may be in other regards.

Possible ways of achieving this ease of standing include shortening the overall length of the suspension (resulting in a shorter stroke) to create a low-down suspension with a low ride height or making the seat cushion thinner. Unfortunately, both options come at a cost in performance.

To overcome this, the new EERA HEIGHTFLEX uses the suspension as a hydraulic jack whereby the movement of the suspension when the motorcycle is in motion extends the jack, increasing the spring preload and raising the ride height. To lower the height, the solenoid valve is opened to release the pressure of oil in the jack chamber (see **Figure 5**).

The system was first used on the Pan America 1250 model of Harley-Davidson, Inc. Its impact has been something of a game changer, with a very favorable reception from both riders and the motorcycle press.

3. 6
Strategy for Expanding Use of Electrically Controlled Suspension into New Areas

As electrically controlled suspension is currently, for the most part, still only available on high-end motorcycles, its scope of application needs to be further expanded if it is to see wider adoption.

In other categories such as small and mid-range models, there is increasing demand for safety and comfort in mid-range models of around 250 cc, which have been growing in popularity in Asia in particular over recent years. Likewise, balancing the cost and functionality of the technology should open up possibilities for its use in smaller two-wheelers where there is a need for improved comfort and differentiation in premium models.

Meanwhile, a growing market is developing mainly in North America for recreational side-by-side (SxS) vehicles and this is another application where electric control is being adopted for suspension. In the future, it will be important to offer optimal packages with special characteristics to suit these different categories.

4. Future Initiatives

The establishment of Hitachi Astemo as a new company has consolidated its leading international share of the markets

for powertrains, brakes, and suspensions for two-wheeled vehicles. Hitachi Astemo also boasts a product lineup that outstrips that of other mega-suppliers, including autonomous driving (AD), ADAS, and other advanced technologies for four-wheeled vehicles.

Hitachi intends to bolster its position as a global leader for two-wheeled vehicles by combining the technologies of key products to create original products that defy imitation by competitors so that, rather than being the sum of these parts, the potential of these products can be further expanded by combining them.

5. Conclusions

This article has described the current state of developments and future prospects for the electrification of two-wheeled vehicles to improve environmental performance and the adoption of electric control for safety and comfort, using electric powertrains, brakes, and suspension as examples.

Hitachi intends to help two-wheeled vehicles find a harmonious place in society while still delivering the joy of riding, not only through the further enhancement of these individual technologies, but also by coordinating their operation to add value and increase the level of environmental performance, safety, and comfort.

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